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Simulation of Industrial Coking - Phase 2

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ABSTRACT

Four statistically designed experimental programs using various Appalachian and Western Canadian coal blends were run in CANMET's 460mm (18 inch) movable wall oven. Coal properties in combination with cokemaking conditions were studied. Factors included coal petrography, rheology, chemistry, bulk density, carbonization rate and final coke temperature. Coke quality parameters including CSR, coal charge characteristics and pressure generation were analyzed. Regressions developed in Phase 1 were improved when coal properties were included in the analysis along with cokemaking conditions.

1. BACKGROUND

As mentioned in "Simulation of Industrial Coking - Phase 1"[1,2], for a fixed coal blend in an industrial wet charged battery, there is limited means to control coke quality. It is desirable to determine the effect and magnitude coke plant operating conditions have on coke quality parameters, especially CSR. Two $2_V^{(5-1)}$ factorial design experiments were performed, one using a typical industrial Appalachian coal blend and the second an equivalent rank Western Canadian coal blend. The factors and levels studied are shown in Table I. Coal rheology and time to perform the experiments were also studied to determine if deterioration in coal properties influenced the final coke results. Six runs were also performed using three center and three standard movable wall oven conditions.

All the data was evaluated statistically using a stepwise regression procedure at a 95% confidence level for the dependent variables and also for the final regression equations.

The conditions chosen were thought to more realistically simulate actual conditions in an industrial oven, especially using oil additions to control bulk density. Highly significant relationships were developed for ASTM and oven bulk density, wall and gas pressure, coke stability, coke size and coke apparent specific gravity (ASG). However, regressions for CSR were less than expected. Coal charge moisture/bulk density was the only significant regressor in the study. Previous work by Canmet[3] had shown that carbonization rate and soak time both influence CSR, but those tests were run under constant coal moisture/bulk density conditions. These results could not be duplicated in Phase 1. Also, coke texture did not change significantly within the heating conditions used. However, there were two distinct levels of CSR between the coal blends used, this being attributed to the differences in coal ash basicity between the blends.

Most coke strength models in the literature are based primarily on coal petrographic properties. Most CSR models are based on coal chemical, rheological and or petrographic properties. Usually, modelling both these coke properties involves using constant standard movable wall oven conditions. However, neither of these two coke quality parameters have been modeled using both coal properties and coking conditions together. For properties like coke size and stability, coking conditions are the most significant factors because the coal properties required, especially for stability, are fixed in a very specific range. This is not necessarily true for coke CSR. If stability is fixed at 60% or greater, coke CSR can vary dramatically depending on the coal ash and ash chemistry, coal rheology, coal petrography and coking conditions used.

By combining coal properties and coking conditions together in one experimental design, we will be able to better understand the interrelationship that exists between them and their combined effect on final coke quality. Factors include coal charge bulk density, carbonization rate to 900°C, final center temperature, coal rank, coal rheology and coal ash chemistry.

Table I Phase 1 Conditions

Factor	Low	High
%-3mm	75	85
$\%H_2O$	3.5	9.0
%Oil	0.0	0.3
Heating Rate to 900°C(mm/hr)	25.4	34.3
Final Center Temperature (°C)	950	1100

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2. EXPERIMENTAL METHODS

2.1 Coking Conditions:

In the previous factorial design program[1,2], five variables were chosen. Based on the statistical analysis of the data, it was found that the variables coal moisture, coal grind and oil additions could be grouped into one variable, bulk density (Table II):

Table II Bulk Density

B. D. Aim	ASTM B. D. (kg/m³)	Coal H2O (%)	Coal %-3mm (%)	Oil (%)
Low	625-657	9.00	85.0	0.00
Center	705	6.25	80.0	0.15
High	785-833	3.50	75.0	0.30

Therefore, it was decided that further studies would contain only three cokemaking variables, i.e. ASTM bulk density, carbonization or heating rate to 900°C and final coke temperature as shown in Table III.

Table III Phase 2 Conditions

Variable	Low	High	Center
ASTM B.D. (kg/cm³)	641	801	721
Heating Rate to 900°C (mm/hr)	25.4	34.3	30.0
Final Center Temperature (°C)	950	1100	1025

This would then be run as a full 2^3 factorial design for a total of eight movable wall oven tests, plus center conditions.

2.2 Coal Properties:

In considering coal properties, the following should be considered[1,2]:

(a) composition: low volatile, medium volatile, high volatile coal composition,
(b) petrography: vitrinite reflectance, reactives, inerts,
(c) rheology: maximum fluidity, fluidity temperature range, contraction, dilation, FSI, days to complete testwork,
(d) chemistry: proximate analysis, ash chemistry.

Other points to be noted in designing the program were that:

(a) Coal blends must meet a minimum 58% predicted stability so that CSR would not be dependent on or restricted by cold strength of the coke,
(b) Inert levels are essentially fixed within a specific range because of restricting coke stability to be a minimum 58%,
(c) Rheological properties are achieved by blending coals. Coal rheological properties were not to be artificially altered by heating them to induce mild oxidation,
(d) There exists a restriction in using a factorial design for coal properties. Consider reflectance, fluidity and ash basicity as seen in Table IV:

Table IV Coal Properties Factorial

Run	Ro (%)	Max. Fluidity (ddpm)	Ash Basicity
1	+	+	+
2	-	+	+
3	+	-	+
4	-	-	+
5	+	+	-
6	-	+	-
7	+	-	-
8	-	-	-

Certain requirements of the design cannot be met because of the nature of coal: for example runs 1, 4, 5 and 8. Using runs 1 and 8 respectively for example, in Appalachian coals if coal reflectance is high i.e. 1.60%, typical fluidity for these coals is less than 500 ddpm and for a low reflectance, i.e. 1.00%, typical fluidity for these coals is greater than 15000 ddpm. Therefore the requirements of the design cannot be met.

One way to avoid this problem is to run 2^3 factorial designs for several blends using the design described for coking conditions. That is, select several blends that would give an adequate range in the above mentioned coal properties in addition to an industrial range in CSR. Blend selection was formulated keeping in mind that the purpose of this study was to simulate "industrial" conditions.

For each coal blend series, a total of 19 runs were performed i.e. 8 for the low blend condition, 8 for the high blend condition and 3 center conditions. Four coal blends were run for this study. The component coals are shown in Table V. The coal blends used are described in Table VI.

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Table V Coal Properties

		APP 6		WCC 7			APP 8		APP/WCC 9				
		COAL L	COAL J	COAL S	COAL LW	COAL F	COAL MM	COAL B	COAL MM	COAL S	COAL LW	COAL F	COAL B
CHEMISTRY													
ASH	(%)	5.30	5.10	6.00	9.70	6.30	5.40	5.50	5.60	7.14	8.99	8.26	5.24
VM	(%)	16.80	35.10	17.50	21.80	31.50	18.80	31.00	18.33	17.48	22.05	27.10	31.14
FC	(%)	77.90	59.80	76.50	68.50	62.20	75.80	63.50	76.07	75.38	68.96	64.64	63.62
S	(%)	0.72	0.96	0.38	0.38	0.45	0.69	0.79	0.80	0.41	0.44	0.67	0.80
SIO2	(%)	47.90	51.30	52.80	59.40	57.80	49.00	53.20	49.16	52.91	59.09	61.68	53.21
AL2O3	(%)	31.10	30.00	30.50	30.80	25.80	33.20	29.70	31.99	29.46	30.50	27.22	30.53
CAO	(%)	3.00	1.10	3.60	1.40	1.80	2.10	1.50	2.33	3.65	1.35	1.68	1.31
MGO	(%)	0.90	0.90	0.30	0.20	0.60	1.00	0.90	1.59	0.52	0.30	0.50	0.96
FE2O3	(%)	9.90	9.50	3.30	2.30	5.90	8.30	6.70	7.04	4.92	3.68	2.94	7.92
K2O	(%)	0.80	2.30	0.40	0.70	1.30	2.10	3.40	2.33	0.57	0.57	1.20	2.39
NA2O	(%)	1.20	0.50	0.90	0.00	0.00	0.70	0.80	0.89	1.01	0.17	0.17	0.63
TIO2	(%)	1.70	1.60	1.50	2.10	1.60	1.30	1.30	1.30	1.32	1.88	1.48	1.50
P2O5	(%)	0.20	0.60	1.40	1.20	1.90	0.60	0.30	0.34	1.17	0.93	1.32	0.26
RHEOLOGY													
FSI		7.5	7.0	4.5	7.0	8.5	8.5	8.0	9.0	7.0	7.0	8.5	7.5
GIESELER													
START	(C)	451	391	-	435	415	443	395	442	458	441	420	395
FUSION	(C)	467	405	-	447	427	461	409	457	-	455	432	411
MAX. FLUID	(C)	478	438	479	463	451	478	447	476	479	473	456	447
FINAL	(C)	497	480	-	487	474	497	485	500	492	489	483	487
SOLID	(C)	502	483	494	490	478	502	488	504	498	493	488	490
FLUID RANGE	(C)	46	89	-	52	59	54	90	58	34	48	63	92
MAX. FLUIDITY	(DDPM)	21	28000	0.9	35	290	24	15700	60	3	15	255	19186
ARNU													
CONTRACT	(%)	31	30	27	25	29	26	25	12	22	28	28	24
DILATION	(%)	25	246	-	10	55	41	260	65	-7	0	69	267
T1	(C)	435	352	444	408	382	415	360	421	429	402	385	352
T2	(C)	467	410	500	456	433	450	405	447	468	449	431	407
T3	(C)	498	468	-	482	465	484	462	483	493	476	461	456
PETROGRAPHY													
V6	(%)	-	-	-	-	-	-	-	-	-	-	-	-
V7	(%)	-	-	-	-	0.80	-	-	-	-	-	-	-
V8	(%)	-	-	-	-	23.40	-	-	-	-	-	-	-
V9	(%)	-	9.80	-	-	37.80	-	-	-	-	-	1.40	5.40
V10	(%)	-	43.40	-	-	11.30	-	5.00	-	-	-	5.00	28.80
V11	(%)	-	16.80	-	9.90	2.30	-	14.90	-	-	-	19.10	28.30
V12	(%)	-	-	-	16.60	-	-	40.30	-	-	0.50	31.90	4.70
V13	(%)	-	-	-	20.70	-	-	10.60	-	-	14.80	11.30	-
V14	(%)	-	-	0.60	4.70	-	0.80	-	-	-	31.10	2.10	-
V15	(%)	7.30	-	14.10	-	-	1.50	-	1.50	1.20	4.60	-	-
V16	(%)	42.20	-	22.70	-	-	16.00	-	14.90	1.30	-	-	-
V17	(%)	16.50	-	15.20	-	-	39.80	-	37.10	33.30	-	-	-
V18	(%)	-	-	4.00	-	-	18.30	-	20.80	13.00	-	-	-
V19	(%)	-	-	-	-	-	-	-	-	1.20	-	-	-
VITRINITE	(%)	66.00	70.00	56.60	51.60	75.60	76.40	70.80	74.30	61.70	51.00	70.80	67.20
EXINITE	(%)	0.00	7.20	0.00	0.00	3.20	0.00	5.60	0.20	0.00	0.30	2.40	6.60
RESINITE	(%)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SEMIFUSINITE	(%)	19.30	11.30	27.80	33.80	12.90	9.90	9.30	9.20	10.20	15.90	10.90	5.80
MICRINITE	(%)	7.30	6.30	4.50	1.90	0.70	5.40	7.00	3.10	5.50	4.60	2.40	10.40
FUSINITE	(%)	4.40	2.20	7.80	6.90	4.10	5.20	4.10	5.40	8.40	7.20	3.30	4.10
MINERAL MATTER	(%)	3.00	3.00	3.30	5.50	3.50	3.10	3.20	3.20	4.00	5.10	4.70	3.00
REACTIVE	(%)	72.40	81.00	70.50	68.80	83.10	79.70	79.50	79.10	71.90	67.20	78.70	76.70
INERT	(%)	27.60	19.00	29.50	31.20	16.90	20.30	20.50	20.90	28.10	32.80	21.30	23.30
MEAN Ro	(%)	1.65	1.05	1.65	1.28	0.94	1.64	1.13	1.65	1.65	1.33	1.13	1.11

Coal L - Appalachian low volatile coal
Coal J - Appalachian high volatile coal
Coal S - Western Canadian low volatile coal
Coal LW - Western Canadian medium volatile coal
Coal F - Western Canadian high volatile coal
Coal MM - Appalachian low volatile coal
Coal B - Appalachian high volatile coal

Table VI Coal Blends

Series	Code	Low	Center	High
Appalachian 6	App 6	15% L / 85% J	25%L / 75% J	35% L / 65% J
Western 7	Wcc 7	10% S / 45% LW / 45% F	20% S / 40% LW / 40% F	30% S / 35% LW / 35% F
Appalachian 8	App 8	15% MM / 85% B	25% MM / 75% B	35% MM / 65% B
Appalachian/ Western Canadian 9	App/Wcc 9	5% L / 5% S / 20% LW/ 35% B / 35% F	10% L / 10% S / 15% LW/ 32.5% B / 32.5% F	15% L / 15% S / 10% LW/ 30% B / 30% F

When analyzing the data from the first three series i.e. App 6, Wcc 7 and App 8, a definite bimodal distribution existed for coal properties because of the inherent differences between Appalachian and Western Canadian coals. The fourth series was used to eliminate this.

2.3 Movable Wall Oven:

Movable wall oven tests are used to simulate the coking process of an industrial coke oven. Conditions are chosen such that the resultant coke shows similar properties to that produced in an industrial oven. At CANMET, the 460 mm movable wall oven is used to study wall and gas pressure and coke quality i.e. size, apparent specific gravity (ASG), cold and hot strength. For the 460 mm movable wall oven, the standard conditions used are as follows:

Coal Grind	80%-3mm
Coal Moisture	3.0-3.5%
Oven Bulk Density	817±8 kg/m^3
ASTM Bulk Density	778 kg/m^3
Constant Flue Temp.	1250°C
Carbonization Rate	34.3 mm/hr to 900°C
Push	3 hours after center temperature reaches 950°C

The coal blend is dried to raise the ASTM bulk density to 778 kg/m^3. This leads to the aim oven bulk density for the movable wall oven. For this series of tests as with an industrial oven, oil additions were used to raise coal charge bulk density.

3. DATA ANALYSIS

3.1 Regression Analysis:

As described in "Simulation of Industrial Coking - Phase 1", anova analysis was not successful for the analysis of the data because of the differences between the aim and actual values. This lead to inconclusive results. It was decided that regression analysis was the preferred method.[1,2]

A stepwise regression procedure was used to analyze the data. For a model to be accepted, the following criterion was used:

a) A 95% minimum confidence level for the model,
b) A 95% minimum confidence level for the dependent variables,
c) Model residuals to have a mean of zero, be normally distributed and be independent,
d) Dependent variables are not to be significantly correlated with each other and,
e) For each effect added to the model, there must be a corresponding decrease in the model root mean square error for the effect to be valid.

Besides the main effects and two factor interactions, other parameters of interest include:

a) Soak Time,
b) Days,
c) Rheology: FSI, total dilation, log maximum fluidity, fluidity temperature range,
d) Petrography: mean maximum reflectance (Ro), inerts, reactives,
(e) Chemistry: coal volatile matter (daf), coal and coke ash, coal and coke basicity, coal and coke ash basicity,
(f) Coke Texture: inerts, coke mosaic size index[4].

Several of these terms and those used in the regressions are defined in Appendix A. Two factor interactions were included only if their main effects were significant.

Other statistical information of importance is:

a) R^2 = Variance accounted for by the model in explaining the response.
b) RMSE = Model root mean square error.

The responses measured include:

a) coal charge properties: bulk density,
b) movable wall oven: pressure (wall, gas), yield,
c) coke quality: size, strength, reactivity, texture.

4. RESULTS

4.1 Main Effects-Phase 1 Methodology:

Regression analysis was performed for each series using the parameters described in Phase 1, i.e. coal moisture, grind, oil, final center temperature, coking rate to 900°C , fluidity and days. This was repeated for each series replacing coal moisture, grind and oil with ASTM bulk density. The data from the four series was then combined into one data set from which the data was further analyzed. The results using Phase 1 methodology for this combined data set is shown in Table VII and Table VIII. Results from the individual series are available from the authors and are not included in this paper.

Results of the analysis showed that the regressions developed in Phase 1 (Appendix 2, Table I) were reproducible in Phase 2. Regression parameters were similar and their associated numerical coefficients were found to be of the same order of magnitude. This is best illustrated when comparing the equations when coal moisture, coal grind and oil additions are combined and included in the regressions as ASTM bulk density (Appendix 2, Table II). With the expanded data base because of using four different coal blends, the statistics such as variance accounted for was lower and the root mean square error higher than in Phase 1. This is a positive result since coal factors, which have not yet been included, are expected to influence the resulting coke quality parameters which will be discussed later in the paper.

Table VII Regression Analysis Using Phase 1 Methodology

Parameter	Intercept	CoalH20	Coal35	Oil	FCTemp	HR900	Days	Prob>F	RMSE	R^2	Range
ASTM B.D. (kg/cm³)	909.243	-33.041	–	–	–	–	–	0.0001	15.984	0.967	589.5-820.0
Oven B.D. (kg/cm³)	895.26	-23.675	–	82.889	–	–	–	0.0001	12.255	0.971	662.2-857.9
Log Max. Wall Pressure	6.54	-0.17	-0.047	–	–	–	–	0.0001	0.594	0.573	0.16-3.88
Log Max. Gas Pressure	4.073	-0.401	–	–	–	–	–	0.0001	0.910	0.544	-0.37-4.41
ASG	0.927	-0.0172	–	–	0.00015	-0.0028	–	0.0001	0.026	0.790	0.788-0.982
Coke Yield (%)	107.992	1.063	-0.507	–	–	–	–	0.0001	2.530	0.281	64.7-78.8
Mean Coke Size (mm)	107.915	–	-0.137	-18.43	–	-0.998	–	0.0001	2.054	0.770	53.6-75.2
+75mm (%)	61.104	–	0.38	-16.33	–	-2.077	0.073	0.0001	4.294	0.767	11.0-44.4
-75+50mm (%)	42.693	0.501	–	–	–	–	-0.073	0.0001	3.458	0.233	35.4-53.4
-25mm (%)	-5.48	-0.166	0.091	–	–	0.096	0.037	0.0001	0.638	0.616	3.3-9.1
Stability (%)	59.041	-0.774	–	–	0.0155	-0.505	-0.034	0.0001	2.597	0.626	43.7-60.8
Hardness (%)	56.834	-1.185	–	8.961	0.0119	–	–	0.0001	1.619	0.874	55.5-70.1
DI30/15 (%)	97.076	-0.161	–	–	–	-0.069	-0.015	0.0001	0.884	0.322	90.5-98.4
DI150/15 (%)	91.348	-0.566	–	–	–	-0.189	–	0.0001	1.777	0.535	74.9-96.3
CSR (%)	65.105	-1.463	–	–	–	–	–	0.0001	5.553	0.305	41.0-69.2
CRI (%)	–	–	–	–	–	–	–	–	–	–	21.5-31.6

Table VIII Regression Analysis Using Bulk Density

Parameter	Intercept	ASTM B.D.	FCTemp	HR900	Days	Prob>F	RMSE	R^2
Log Max. Wall Pressure	-3.888	0.0080	–	–	–	0.0001	0.579	0.598
Log Max. Gas Pressure	-7.208	0.0125	–	–	–	0.0001	0.864	0.589
ASG	0.407	0.0005	0.00016	-0.0021	–	0.0001	0.022	0.842
Coke Yield (%)	74.810	–	–	–	-0.046	0.0175	2.692	0.075
Mean Coke Size (mm)	112.790	-0.022	–	-1.094	–	0.0001	2.228	0.723
+75mm (%)	125.158	-0.047	–	-2.174	0.085	0.0001	4.647	0.727
-75+50mm (%)	55.516	-0.014	–	–	-0.066	0.0001	3.506	0.211
-25mm (%)	0.392	–	–	0.108	0.039	0.0001	0.704	0.523
Stability (%)	37.180	0.025	0.014	-0.480	-0.036	0.0001	2.519	0.653
Hardness (%)	15.220	0.050	0.013	–	-0.019	0.0001	1.370	0.909
DI3015 (%)	92.319	0.005	–	-0.063	-0.016	0.0001	0.875	0.336
DI150/15 (%)	72.464	0.020	–	-0.128	-0.024	0.0001	1.646	0.593
CSR (%)	22.729	0.049	–	–	-0.069	0.0001	5.163	0.399
CRI (%)	31.922	-0.008	–	–	–	0.0519	2.835	0.049

Similar to the results in Phase 1, oil additions of 0.15% and 0.30% at 6% and 9% coal moisture, respectively, were not adequate in raising the ASTM bulk density to the standard 3.5% moisture of 778 kg/m³ or the oven bulk density to 817 kg/cm³. Coal moisture was the most predominate factor for both the ASTM and oven densities.

From Tables VII and VIII, the major influence that coal moisture, hence bulk density, has on subsequent coke quality is clearly demonstrated. High moisture levels i.e. low bulk density, lead to a decrease in coke ASG, strength and CSR. Lower charge bulk density lead to lower wall and gas pressures as seen in Figure 1. Similar to Phase 1, at 6% and 9%, there were no significant differences between the blends and the pressures were quite low.

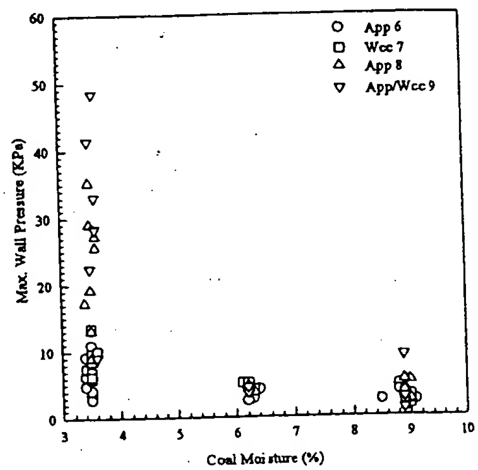

Figure 1 Max. Wall Pressure versus Coal Moisture

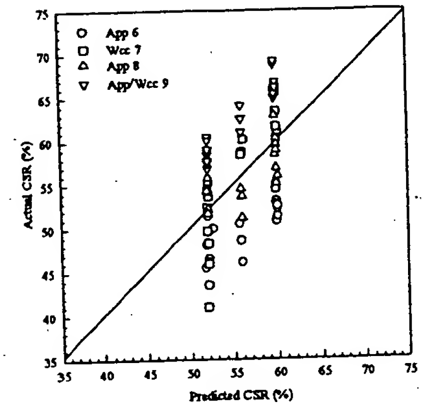

Figure 2 Actual CSR versus Predicted CSR

For coke ASG, cold strength and size, the effect of a slower coking rate or heating rate is also seen along with a high and adequate final center temperature. The influence of days which represents some form of deterioration in coal rheological properties is also indicated. Coal storage time lead to a lower coke quality, in particular coke size, cold strength and CSR. Similar to Phase 1, CSR was strongly influenced by the coal moisture levels used. This is shown in Figure 2. The influence of the other cokemaking variables were not significant, however, the analysis did not include coal properties at this time.

Coke ASG relationships developed in Phase 1 were repeated for each coal blend series and the results are shown in Table IX. The relationships between log wall pressure, stability, hardness and CSR are shown in Figures 3-6.

Table IX ASG Relationships

Parameter	Code	Intercept	ASG	Prob>F	RMSE	R^2
Log Max. Wall Pressure	App 6	-5.586	7.782	0.0032	0.378	0.408
	Wcc 7	-6.749	9.107	0.0001	0.289	0.826
	App 8	-14.822	19.846	0.0001	0.443	0.782
	App/Wcc 9	-12.688	16.577	0.0001	0.696	0.670
Log Max. Gas Pressure	App 6	-14.631	17.568	0.0010	0.733	0.483
	Wcc 7	-9.785	12.449	0.0032	0.638	0.562
	App 8	-22.329	28.780	0.0001	0.746	0.728
	App/Wcc 9	-17.129	21.345	0.0001	1.024	0.608
Mean Coke Size (mm)		–	–	–	–	–
Stability (%)	App 6	5.113	51.350	0.0087	2.848	0.358
	Wcc 7	-1.621	59.708	0.0001	2.109	0.793
	App 8	12.490	49.045	0.0042	2.592	0.391
	App/Wcc 9	-0.329	62.464	0.0001	2.324	0.721
Hardness (%)	App 6	-10.331	81.124	0.0001	1.878	0.752
	Wcc 7	-5.736	75.735	0.0001	1.202	0.951
	App 8	-14.042	90.360	0.0001	1.693	0.836
	App/Wcc 9	-8.241	81.042	0.0001	1.321	0.931
DI3015 (%)	App 6	87.752	5.838	0.1669	0.668	0.116
	Wcc 7	79.734	14.608	0.0001	0.646	0.710
	App 8	89.520	5.519	0.0845	0.526	0.165
	App/Wcc 9	85.644	9.670	0.0011	0.556	0.519
DI150/15 (%)	App 6	49.641	35.530	0.1027	3.429	0.149
	Wcc 7	44.878	39.326	0.0001	1.207	0.836
	App 8	61.211	24.786	0.0013	1.123	0.466
	App/Wcc 9	55.627	30.095	0.0001	0.886	0.805
CSR (%)	App 6	-14.316	72.042	0.0001	1.876	0.706
	Wcc 7	-26.888	92.528	0.0001	3.839	0.736
	App 8	-0.863	66.441	0.0001	1.883	0.691
	App/Wcc 9	6.364	63.421	0.0001	1.652	0.841
CRI (%)	App 6	33.534	-4.731	0.6051	1.490	0.016
	Wcc 7	49.442	-25.850	0.0001	1.544	0.573
	App 8	27.815	0.540	0.9220	0.949	0.001
	App/Wcc 9	26.081	-3.682	0.2891	0.803	0.070

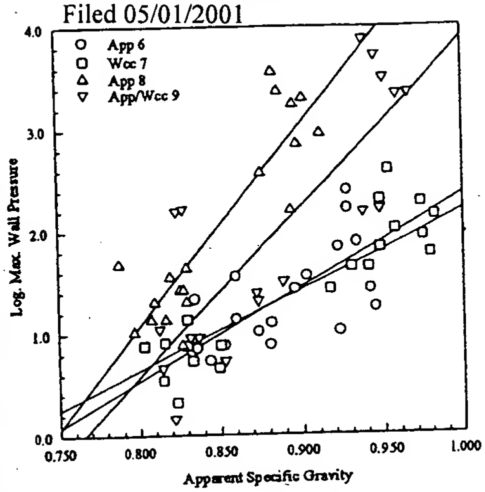

Figure 3 Log Max. Wall Pressure versus ASG

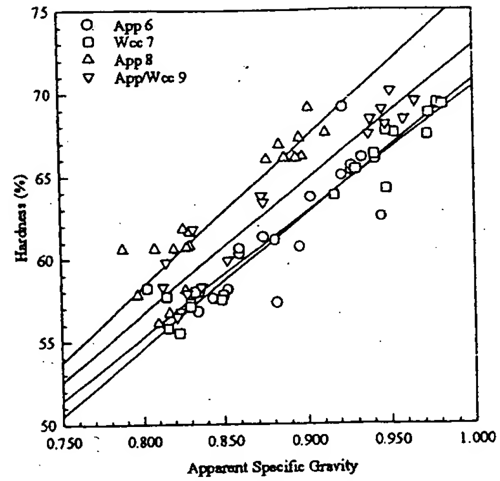

Figure 5 Hardness versus ASG

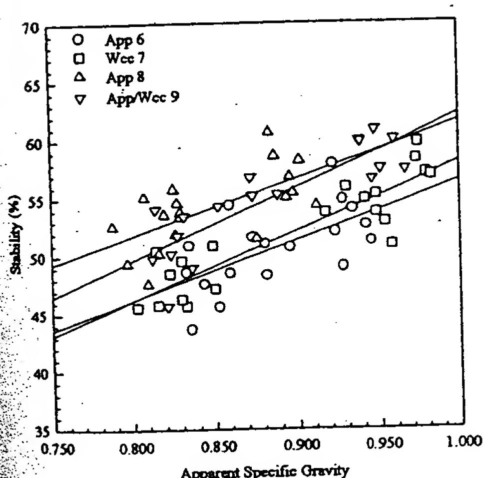

Figure 4 Stability versus ASG

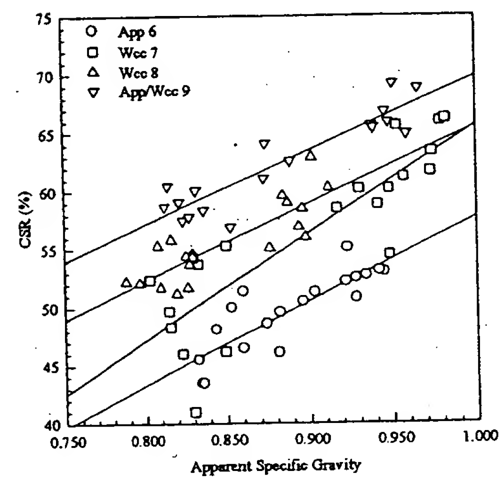

Figure 6 CSR versus ASG

In Phase 1, it was stated that ASG is a fundamental measurement of coke structure. It can be used to relate coke quality parameters together and also confirm coal charge bulk density and heating conditions. As shown in the above figures, this is very true. In fact, for stability, hardness and CSR, there is a general parallelism between the various blends in this relationship under these simulated conditions indicating there is some degree of independence on coal blend. For wall pressure, there is a greater dependence on coal blend. This is expected considering that both Appalachian and Western Canadian coals have been used. These coal types have known differences in vitrinite, reactive semifusinite and inert levels. Conditions that lead to higher ASG also lead to higher wall and gas pressures.

4.2 Main Effects-Phase 2 Methodology:

Although several valid statistical relationships have been developed in Phase 1 and reproduced so far in Phase 2, the main intent of this work was to investigate coal properties in conjunction with cokemaking conditions under industrial similar conditions. A better understanding is desired about the interrelationship that exists between them and their final effect on coke quality.

When terms are added to the regressions, they must make sound, fundamental sense. The intention was not to improve the statistics for the sake of improved mathematics. Close attention has been paid to the multicollinearity that does exist between several of the variables and rules outlined in Section 3.1 have been adhered to. There exists no perfect solution for these regressions and several of them could have been developed slightly different from what is presented. For example, there are many ways to represent coal rank. Coal reflectance, coal volatile matter (daf) and even coke mosaic size index are all possibilities. When coal or coke inerts were used, the preference was to use coke inerts because of the higher estimated reactivity of the Western Canadian coal semifusinite compared to similar ranked Appalachian coals. When the regressions were performed, the decision was to use the most conventional property such that application of these equations could be performed in a typical industrial situation. The parameters in the following equations are listed by cokemaking parameters first and coal properties second.

4.21 Wall Pressure:

Wall pressure was derived using log wall pressure. Wall pressure was explained by the following equation using coal charge bulk density, coal rank and coke inerts:

Log Wall Pressure = -10.259 + 0.0083 (ASTM B.D.) + 5.249 (Ro) - 0.0199 (Coke Inerts)

R^2=0.746 RMSE=0.466 Prob>F=0.0001 (i)

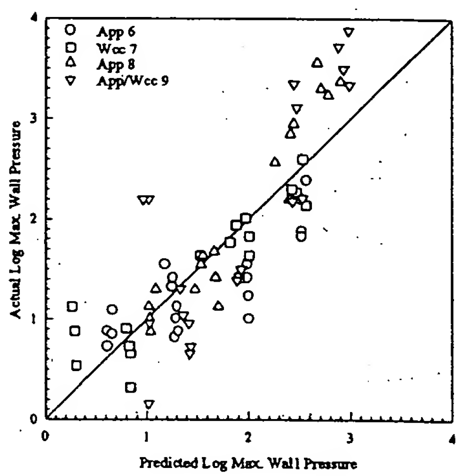

Figure 7 Actual Log Max. Wall Pressure versus Predicted Log Max. Wall Pressure

A decrease in coal charge bulk density and coal rank along with an increase in coke inerts resulted in a lower wall pressure. The coefficient for bulk density was similar to what was reported in Table VIII. The partial r^2's indicate that bulk density at 62% was the most predominate factor.

4.22 Gas Pressure:

Gas pressure was derived using log gas pressure. Gas pressure was explained by the following equation using charge bulk density and coal rank:

Log Gas Pressure = -16.567 + 0.0124 (ASTM B.D.) + 7.628 (Ro)

R^2=0.688 RMSE=0.758 Prob>F=0.0001 (ii)

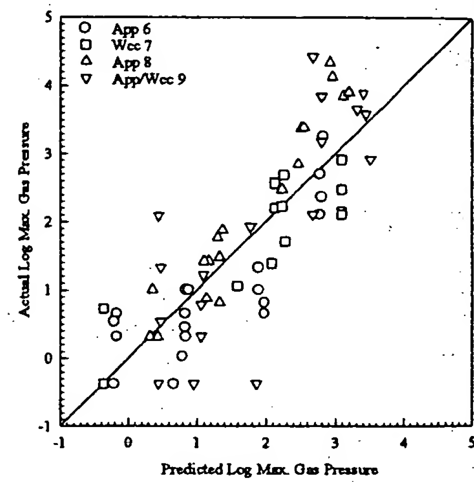

Figure 8 Actual Log Max. Gas Pressure versus Predicted Log Max. Gas Pressure

A decrease in coal charge density and coal rank resulted in a lower gas pressure. The coefficient for bulk density was similar to what was reported in Table VIII. The partial r^2's indicate that bulk density at 59% was the most predominate factor.

4.23 Apparent Specific Gravity:

Apparent specific gravity was explained by the following equation using coal charge bulk density, heating rate to 900°C, final center temperature, coal rank and coke inerts:

ASG = 0.444 + 0.00057 (ASTM B.D.) -0.0015 (HR900) + 0.00014 (FCTemp) - 0.077 (Ro) + 0.0020 (Coke Inerts)

R^2=0.907 RMSE=0.0176 Prob>F=0.0001 (iii)

An increase in coal charge bulk density, slower heating rate,

higher final center temperature, lower coal rank and increased coke inerts resulted in a higher coke ASG. The coefficients for bulk density, heating rate and final center temperature were similar to what was reported in Table VIII. The partial r^2's indicate that bulk density at 83% was the most predominate factor.

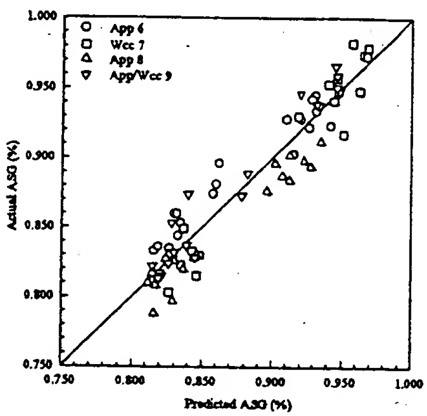

Figure 9 Actual ASG versus Predicted ASG

4.24 Coke Yield:

Coke yield was explained by the following equation using coal charge bulk density, coal fluidity range, coal rank and coal inerts:

Coke Yield (%) = -7.165 + 0.0064 (ASTM B.D.) + 0.193 (Fluid Range) + 30.051 (Ro) + 1.122 (Coal Inerts)

R^2=0.724 RMSE=1.569 Prob>F=0.0001 (iv)

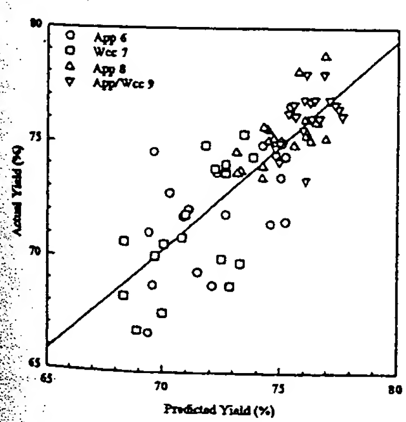

Figure 10 Actual Coke Yield versus Predicted Coke Yield

An increase in coal charge bulk density, wider coal fluidity range, higher coal rank and increased coal inerts resulted in a higher coke yield. It should be noted that in Table VIII, with out coal properties being included, a significant regression was unsuccessful. The partial r^2's indicate that coal rank at 47% was the most significant factor with both fluidity range and coal inerts accounting for 10% respectively to the model. With a narrow range in yield of 65 to 79% since industrial based blends were used, this limited range can make it difficult to develop a more significant relationship for yield.

4.25 Coke Size:

Mean coke size was explained by the following equation using coal charge bulk density, heating rate to 900°C, soak time and coke inert levels:

Mean Coke Size (mm) = 112.710 - 0.0209 (ASTM B.D.) - 1.056 (HR900) + 0.345 (Soak Time) - 0.133 (Coke Inerts)

R^2=0.778 RMSE=1.922 Prob>F=0.0001 (v)

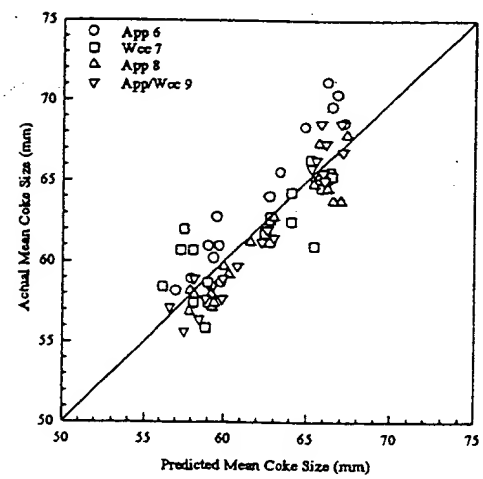

Figure 11 Actual Mean Coke Size versus Predicted Mean Coke Size

A decrease in coal charge bulk density, slower heating rate, longer soak time and lower level of coke inerts resulted in a higher mean coke size. The coefficients for bulk density and heating rate were similar to what was reported in Table VIII. The partial r^2's indicate that heating rate at 59% was the most predominate factor followed by bulk density at 14%.

For the size fractions measured, the following equations were developed:

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+75mm (%) = 131.124 - 0.0392 (ASTM B.D.) - 2.178 (HR900) - 4.009 (Coal Ash) + 0.913 (Coke Inerts)

R^2=0.841 RMSE=3.644 Prob>F=0.0001 (vi)

-75+50mm (%) = 63.105 - 0.0168 (ASTM B.D.) - 0.0425 (Days) + 16.863 (Ro) - 2.174 (Coal Inerts) + 3.541 (Coal Ash)

R^2=0.480 RMSE=2.909 Prob>F=0.0001 (vii)

-25mm (%) = 4.933 + 0.0957 (HR900) + 0.0539 (Coke Inerts) + 0.0298 (Days) - 4.011 (Ro)

R^2=0.670 RMSE=0.591 Prob>F=0.0001 (viii)

4.26 Stability:

Stability was explained by the following equation using coal charge bulk density, heating rate to 900°C, final center temperature, days to perform tests and coal rank:

Stability (%) = 0.0562 + 0.0245 (ASTM B.D.) - 0.493 (HR900) + 0.0150 (FCTemp) - 0.0243 (Days) +30.008 (Ro)

R^2=0.845 RMSE=1.691 Prob>F=0.0001 (ix)

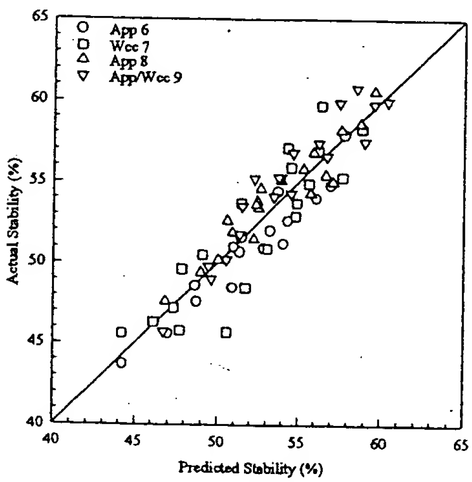

Figure 12 Actual Stability versus Predicted Stability

An increase in coal charge bulk density, slower heating rate, higher final center temperature, decreased coal storage time and higher coal rank resulted in a higher stability. The coefficients for bulk density, heating rate, final center temperature and days were similar to what was reported in Table VIII. The partial r^2's indicate that bulk density at 54% was the most predominate factor followed by coal rank at 16% and heating rate at 10%.

4.27 Hardness:

Hardness was explained by the following equation using coal charge bulk density, final center temperature and coal rank:

Hardness (%) = 1.473 + 0.0488 (ASTM B.D.) + 0.0147 (FCTemp) + 9.855 (Ro)

R^2=0.920 RMSE=1.291 Prob>F=0.0001 (x)

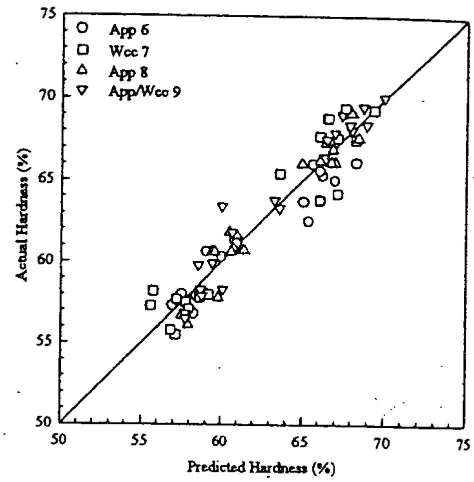

Figure 13 Actual Hardness versus Predicted Hardness

An increase in coal charge bulk density, higher final center temperature and higher coal rank resulted in a higher hardness. The coefficients for bulk density and final center temperature were similar to what was reported in Table VIII. The partial r^2's indicate that bulk density at 87% was the most predominate factor in explaining hardness. Although days fell out of this equation, it only contributed 0.5% to the equation shown in Table VIII.

4.28 DI 30/15:

DI 30/15 was explained by the following equation using coal charge bulk density, heating rate, final center temperature, coal rank, coke ash and coke inerts:

DI 30/15 (%) = 80.348 + 0.0025 (ASTM B.D.) - 0.0979 (HR900) + 0.00377 (FCTemp) + 7.733 (Ro) + 0.448 (Coke Ash) - 0.138 (Coke Inerts)

R^2=0.699 RMSE=0.613 Prob>F=0.0001 (xi)

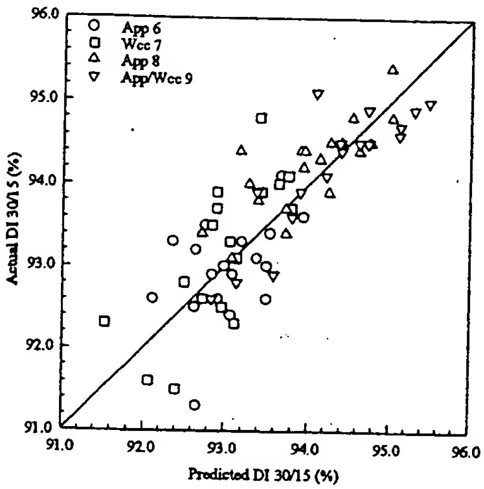

Figure 14 Actual DI 30/15 versus Predicted DI 30/15

An increase in coal charge bulk density, slower heating rate, higher final center temperature, higher coal rank, increased coke ash lower coke inert levels resulted in a higher DI 30/15. The coefficients for bulk density and heating rate were similar to what was reported in Table VIII. The partial r^2's indicate that coal rank at 20% was the most predominate factor followed by bulk density at 18%, coke ash at 12% and coke inert levels at 10% in explaining DI 30/15. Although days fell out of this equation, it only contributed 6% to the equation shown in Table VIII.

4.29 DI 150/15:

DI 150/15 was explained by the following equation using coal charge bulk density, soak time, coke inerts and coal rank:

DI 150/15 (%) = 47.800 + 0.0221 (ASTM B.D.) + 0.256 (Soak Time) - 0.0959 (Coke Inerts) + 15.725 (Ro)

R^2=0.710 RMSE=1.444 Prob>F=0.0001 (xii)

An increase in coal charge bulk density, longer soak time, lower coke inert levels and higher coal rank resulted in a higher DI 150/15. The coefficient for bulk density was similar to what was reported in Table VIII. The partial r^2's indicate that bulk density at 53% was the most predominate factor followed by coal rank at 12% in explaining DI 150/15. Although heating rate and days fell out of this equation, they only contributed 2.5% respectively to the equation shown in Table VIII. Soak time shows up in Equation xii, but only contributes 2% to the overall variance accounted for.

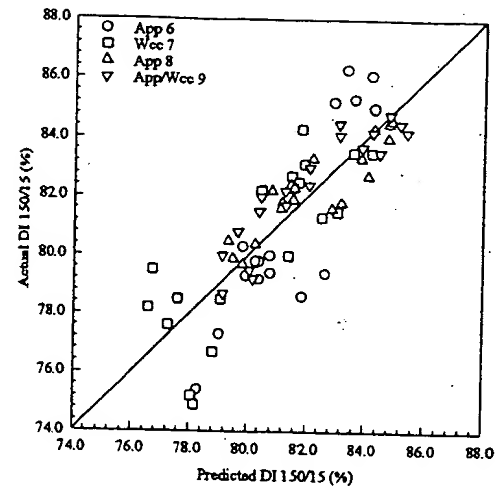

Figure 15 Actual DI 150/15 versus Predicted DI 150/15

4.30 CRI:

CRI was explained by the following equation using coal charge bulk density, final center temperature, coal rank, coke inerts and coke ash basicity index:

CRI (%) = 17.468 + 0.120 (HR900) - 0.0121 (FCTemp) + 0.165 (Coke Inerts) + 13.935 (Coke AB Index)

R^2=0.797 RMSE=1.313 Prob>F=0.0001 (xiii)

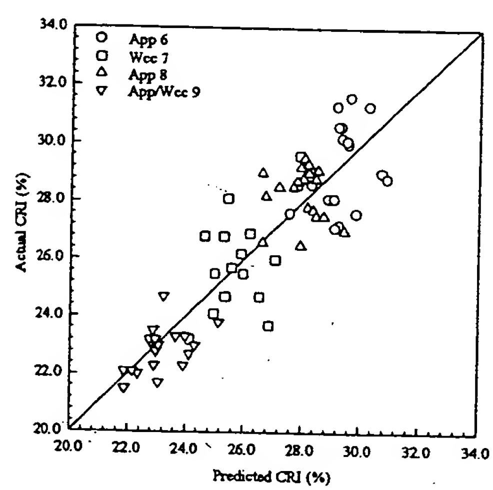

Figure 16 Actual CRI versus Predicted CRI

An increase in heating rate, lower final center temperature, increased coke inert levels and a higher coke ash basicity index resulted in a higher CRI index. Although bulk density dropped out of the equation as shown in Table VIII, it only accounted for 5% and was marginally significant. The partial r^2's indicate that coke ash basicity index at 68% was the most predominate factor followed by coke inert levels at 6%. Heating rate and final center temperature at 2.4% and 3.7% respectively were minor contributors to the CRI index. Variance accounted for increased from 5% in Table VIII to 80% when coal properties were included. In Figure 16, the four distinct levels of ash basicity index can be seen for the coal blends used.

4.31 CSR:

CSR was explained by the following equation using coal charge bulk density, coal rank, final center temperature, coke basicity index and coke inerts:

CSR (%) = 17.403 + 0.0404 (ASTM B.D.) + 16.106 (Ro) + 0.0235 (FCTemp) - 154.161 (Coke Basicity Index) - 0.644 (Coke Inerts)

R^2=0.840 RMSE=2.590 Prob>F=0.0001 (xv)

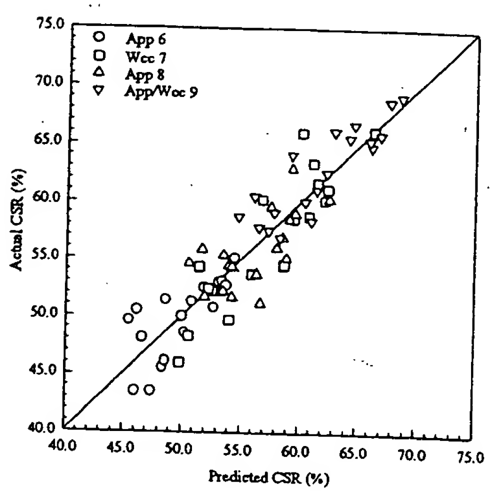

Figure 17 Actual CSR versus Predicted CSR

An increase in coal charge bulk density, higher coal rank, higher final center temperature, lower coke basicity index and lower coke inert levels resulted in a higher CSR index. The coefficient for bulk density was similar to what was reported in Table VIII. The partial r^2's indicate that bulk density at 33% was the most predominant factor followed by the coke basicity index at 28% and coke inert levels at 17% in explaining CSR. Coal rank and final center temperature at 1.9% and 4.6% respectively were minor contributors to the CSR index. Variance accounted for increased from 39.9% in Table VIII to 84.0% when coal properties were included. Although days fell out of this equation, it only contributed 3% to the equation shown in Table VIII. If one compares Figure 2 with Figure 17, a significant improvement can be seen.

Coke mosaic size index could have been used instead of coal reflectance (Ro), but since rank was not a strong contributor, it was decided to use the most conventional parameter.

A very significant relationship can be seen in Figure 18 between CSR and hardness for each coal blend used:

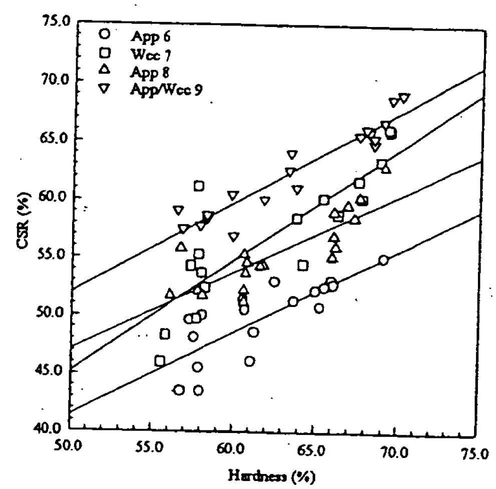

Figure 18 CSR versus Hardness

This relationship is reasonable if the CSR and hardness regressions are compared. The combined effect of bulk density, final center temperature and coal rank are major contributors to each of their developed equations respectively.

4.32 Coke Mosaic Size Index:

The coke mosaic size index which is an indication of the order of the coke structure was calculated from the corresponding coke texture analysis. A regression equation was developed as follows:

CMSI = -2.636 + 0.00028 (ASTM B.D.) + 0.0096 (HR900) + 0.0177 (Soak Time) + 4.023 (Ro)

R^2=0.874 RMSE=0.087 Prob>F=0.0001 (xvi)

Higher charge bulk density, faster heating rate, longer soak time and higher coal rank lead to a higher coke mosaic size index. Mosaic size index was very much dependent on coal rank which accounted for 84% of the variance accounted for.

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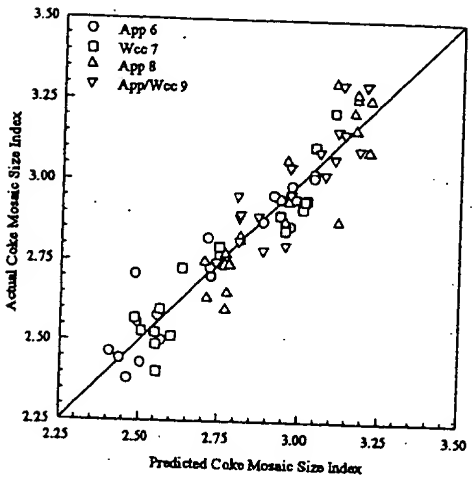

Figure 19 Actual CMSI versus Predicted CMSI

5. DISCUSSION

The conditions chosen were thought to realistically imulate actual conditions in an industrial oven, especially sing oil additions to control bulk density.[1,2] Significant :gressions were developed for ASTM bulk density, oven bulk ensity, wall and gas pressures, coke ASG, coke size and size stribution, stability, hardness, DI 30/15, DI 150/15, CSR, RI and coke mosaic size index.

Regressions developed in Phase 1, were repeatable in iase 2. Regression parameters and their associated imerical coefficients were very similar in Phase 2 using iase 1 methodology. Increased coal moisture resulted in creased charge bulk density, oven pressures and coke iality such as strength, ASG and CSR. The importance of al moisture and bulk density control can be seen in Tables I and VIII. A slow heating rate and high final center nperature had a positive effect on ASG, coke strength and ke size. Coal storage time had a negative effect on »sequent coke quality. The importance of coke ASG as a itrol parameter can be also seen in table IX. Significant G regressions were developed for wall and gas pressures, :e strength and CSR.

In the development of Phase 2 regressions, when coal ameters were added to the originally derived Phase 2 ressions, the cokemaking parameters such as bulk density, l center temperature and heating rate and their associated ierical coefficients were similar to those originally derived. s indicates the independence that these parameters have in development of these regressions and how important it is ontrol these during cokemaking. As seen in the developed ations, when coal properties were added, variance accounted for increased and root mean square of the equations decreased.

Of all the coal properties added, coal rank was the most significant. Increased coal blend rank (Ro=1.14-1.30%) resulted in higher wall and gas pressures along with lower ASG, higher coke yield, stability, hardness, DI 30/15, DI 150/15 and CSR.

Coke inerts were also significant. It must be considered that in this program Western Canadian coals have been used and that the coal blend inert levels might be higher than levels used for 100% Appalachian industrial blends. Higher coke inert levels lead to decreased wall pressures, higher coke density, smaller coke size, lower DI 150/15 and lower DI 30/15. CRI increased and CSR decreased.

For the coals used and the time frame that the program was completed in, decreased rheological properties were not major contributors to the regressions. Since the coal blends were fixed in an industrial range, rheological property range was limited. One should also consider the fact that Western Canadian coals, although having lower rheological properties than comparable Appalachian coals, will still make coke of excellent quality as seen in this study and in Phase 1. Where coal rheological properties were significant, it was found that a high degree of multicollinearity existed among several of the coal parameters. For example coal rank and maximum fluidity are highly correlated. The preference was to use rank in this study when this situation arose. In the equations that days to complete the study was significant, this indicated that coal rheology was important and must be considered, however, we were not able to represent this with the conventional rheological test parameters. By examining the statistics i.e. variance accounted for, for the regressions in this study, it can be stated that the largest contributors have been identified. The effect that coal rheological properties would have on these equations is thought to be not as significant.

In the development of CRI and CSR equations, there has been very significant improvements in these regression with the addition of coal parameters. Besides the importance of coal charge bulk density, the importance of coke ash chemistry expressed as a basicity ratio on CRI and CSR was clearly demonstrated. Also demonstrated was the important interrelationship between CSR and hardness. The factors that control hardness, assuming an adequate coal ash chemistry, will also effect CSR.

6. INDUSTRIAL APPLICATIONS

With the trend in North America and in fact around the world to higher productivity blast furnaces, the demands on coke quality are increasing. With higher levels of injectant, there is a trend to lower coke rates and the coke being used must be of superior quality in both level and consistency. High cold and hot strength, adequate size and tight size

distribution, ability to maintain its integrity and resist breakdown to and within the blast furnace is becoming a standard requirement being asked of cokemakers today. With the completion of this program, it is desired that potential for coke quality improvements be recognized and an action plan conceived such that these demands can be met.

As previously discussed in "Simulation Of Industrial Coking - Phase 1"[1], Dofasco has an ongoing study to measure and reduce the variation of cokemaking parameters that affect coke quality, hence blast furnace performance. To date work has been ongoing in measuring and controlling :

- coal moisture,
- coal bulk density,
- carbonization rate and
- final coke temperature.

From Phase 2, additional parameters include coal rank, inert levels and coke ash chemistry. To start, Dofasco is investigating coals with higher inert levels and a more favourable ash chemistry to improve ASG and CSR respectively.

7. CONCLUSIONS

1a) Coal moisture influenced all responses measured. Increased coal moisture resulted in a lower coal charge bulk density, strength, ASG, CSR and wall and gas pressures.

b) Oil additions were not adequate in maintaining charge bulk densities at higher moisture levels.

c) Lower charge bulk density resulted in lower wall and gas pressures and lower coke strength, ASG, yield and CSR.

d) Slower heating rates resulted in increased coke size, strength and ASG.

e) Higher final center temperature resulted in increased ASG, strength and CSR.

2) Coal rank was the most predominant coal factor. Increased coal rank resulted in an increase in wall and gas pressures, lower ASG, higher yield, strength and CSR.

3) Inert levels were significant contributors to coke quality. Increased inert levels resulted in lower wall and gas pressures, higher ASG, yield, lower coke size, strength and CSR.

4) Coke ash chemistry was a major factor in explaining coke CRI and CSR.

5) When coal properties were added to the existing cokemaking regressions, these cokemaking parameters and their associated coefficients were retained in the regression and were numerically similar.

8. ACKNOWLEDGMENTS

The authors would like to thank the Canadian Carbonization Research Association and its member companies for their support, the staff of CANMET for conducting the research and the Federal Program on Energy Research and Development for funding. A special thank you to Dofasco's Coke Plant personnel for carrying out the ongoing implementation of this work.

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APPENDIX A

Terms used in the regression analysis are defined as follows:

a) CoalH2O	=Coal H_2O (%)
b) Coal35	=Coal -3.5mm (%)
c) Oil	=Oil addition (%)
d) FCTemp	=Final Center Coke Temperature (°C)
e) HR900	=Coking Rate to 900°C (mm/hour)
f) Soak Time	=Gross Coking Time-Time to 950°C (hour)
g) Fluid	=Coal Blend Log Maximum Fluidity
h) Days	=Defined as the number of days to perform the movable wall oven test work with the first movable wall oven test labelled zero (days)
i) Ro	=Mean maximum vitrinite reflectance (%)
j) Coke AB Index	=CokeAsh*(CaO+MgO+Fe2O3+K2O+Na2O)/ (SiO2+Al2O3)
k)Basicity Index	=(CaO+MgO+Fe2O3+K2O+Na2O)/ (SiO2+Al2O3)
l) Fluid Range	=Temperature range measured from softening to resolidification in Gieseler test
m) Coke Inerts	=Measured microscopically by point counting
n) CMSI	=[(very fine mosaic) + 2(fine mosaic+medium mosaic) + 3(course mosaic+fine flow+medium flow) + 4(course flow+fine ribbon) + 5(medium ribbon+course ribbon)]/[100-isotropic-inerts]

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APPENDIX B

Table I Phase 1 Regression Analysis

Parameter		Intercept	CoalH20	Coal35	Oil	FCTemp	HR900	Days	Fluid	Prob>F	RMSE	R^2	Range
ASTM B.D.	A	1033.698	-26.594	-1.957	55.275	–	–	–	–	0.0001	14.90	0.960	625.0-833.0
(kg/cm^3)	W	858.441	-18.503	–	219.953	–	–	–	–	0.0001	27.33	0.841	609.0-817.0
Oven B.D.	A	913.879	-23.691	–	–	–	–	–	–	0.0001	8.12	0.983	697.0-852.0
(kg/cm^3)	W	898.223	-18.596	–	80.929	–	–	-0.373	–	0.0001	14.91	0.926	705.0-846.9
Log Max.	A	4.021	-0.349	–	–	–	–	–	–	0.0001	0.382	0.853	-1.14-1.39
Wall Pressure	W	2.720	-0.175	–	0.883	–	–	–	–	0.0001	0.214	0.827	1.11-2.64
Log Max.	A	5.619	-0.550	–	–	–	–	–	–	0.0001	0.377	0.937	-1.61-2.57
Gas Pressure	W	2.534	-0.313	–	–	–	–	–	–	0.0050	0.909	0.398	-0.73-2.74
ASG	A	0.940	-0.0148	-0.0014	–	0.00022	-0.0026	–	–	0.0001	0.013	0.942	0.800-0.948
	W	0.933	-0.0144	–	0.0881	–	–	–	–	0.0001	0.013	0.898	0.847-0.962
Yield	A	–	–	–	–	–	–	–	–	–	–	–	72.0-77.4
(%)	W	–	–	–	–	–	–	–	–	–	–	–	72.8-81.6
Mean Coke	A	92.745	0.778	–	–	–	-1.206	–	–	0.0001	1.16	0.928	53.6-64.5
Size(mm)	W	95.861	–	–	-6.060	–	-1.244	–	–	0.0001	1.19	0.929	51.1-64.5
+75mm	A	75.458	1.192	–	–	–	-2.005	–	–	0.0001	1.71	0.945	7.5-30.1
(%)	W	70.291	–	–	–	–	1.738	–	–	0.0001	2.97	0.810	8.5-30.6
-75+50mm	A	–	–	–	–	–	–	–	–	–	–	–	35.4-53.4
(%)	W	58.736	–	–	–	–	-0.596	–	–	0.0001	1.94	0.540	35.2-45.7
-25mm	A	0.995	–	–	–	–	0.123	–	–	0.0001	0.30	0.675	3.9-6.0
(%)	W	2.980	0.224		-1.756	–	0.077	–	–	0.0001	0.49	0.691	53.-8.0
Stability	A	52.484	-1.067	0.098	–	0.021	-0.577	–	–	0.0001	1.24	0.924	48.6-63.1
(%)	W	51.131	-1.089	0.235	–	0.017	-0.786	-0.060	–	0.0001	1.63	0.894	46.1-62.6
Hardness	A	60.488	-1.563	-0.091	–	0.021	–	-0.018	–	0.0001	0.66	0.980	57.8-70.7
(%)	W	77.005	-1.422	–	–	–	–	-0.084	–	0.0001	2.14	0.803	56.6-70.6
DI30/15	A	92.605	-0.096	0.019	–	0.0032	-0.084	–	–	0.0001	0.22	0.835	91.2-95.1
(%)	W	95.005	-0.331	–	2.116	–	–	–	–	0.0001	0.61	0.684	90.8-94.7
DI150/15	A	83.400	-0.470	–	–	0.0065	-0.127	-0.016	–	0.0001	0.50	0.917	79.7-84.9
(%)	W	77.900	-0.852	0.089	4.492	0.0067	-0.160	-0.044	–	0.0001	0.87	0.927	75.5-85.5
CSR	A	61.301	-1.233	–	–	–	–	–	–	0.0001	1.67	0.788	47.7-59.9
(%)	W	72.602	-1.674	10.284	–	–	–	-0.099	–	0.0001	2.61	0.811	48.9-66.1
CRI	A	33.083	0.018	–	–	–	–	–	–	0.0173	1.11	0.321	27.5-31.7
(%)	W	22.287	0.325	–	-3.691	–	–	0.0401	-0.003	0.0001	0.81	0.759	23.2-28.3

A=Appalachian Blend W=Western Canadian Blend

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APPENDIX B

Table II Phase 1 ASTM Bulk Density Regression Results

Parameter		Intercept	ASTM B.D.	FCTemp	HR900	Days	Prob>F	RMSE	R^2
Log Max. Wall Pressure	A	-7.514	0.013	–	–	–	0.0001	0.397	0.845
	W	-2.848	0.006	–	–	–	0.0001	0.300	0.643
Log Max. Gas Pressure	A	-12.054	0.020	–	–	–	0.0001	0.458	0.904
	W	-6.338	0.010	–	–	–	0.0001	1.007	0.262
ASG	A	0.357	0.0006	0.00017	-0.0021	–	0.0001	0.010	0.963
	W	0.526	0.0005	–	–	–	0.0001	0.021	0.719
Mean Coke Size (mm)	A	120.193	-0.030	–	-1.236	–	0.0001	1.043	0.942
	W	102.398	-0.012	–	-1.196	–	0.0001	1.251	0.923
+75mm (%)	A	119.643	-0.048	–	-2.074	–	0.0001	2.122	0.917
	W	89.472	-0.024	–	-1.782	–	0.0001	2.602	0.861
-75+25mm (%)	A	–	–	–	–	–	–	–	–
	W	58.736	–	–	-0.596	–	0.0001	1.938	0.540
-25mm (%)	A	0.995	–	–	0.123	–	0.0001	0.300	0.675
	W	10.793	-0.009	–	0.079	–	0.0001	0.497	0.660
Stability (%)	A	26.417	0.038	0.019	-0.541	–	0.0001	1.593	0.867
	W	35.508	0.044	–	-0.489	–	0.0001	2.873	0.610
Hardness (%)	A	7.658	0.058	0.015	–	–	0.0001	0.974	0.952
	W	22.765	0.058	–	–	–	0.0001	1.972	0.793
DI30/15 (%)	A	91.701	0.003	0.0032	-0.086	–	0.0001	0.279	0.729
	W	83.021	0.014	–	–	–	0.0001	0.570	0.711
DI15015 (%)	A	73.537	0.017	–	-0.110	–	0.0001	0.729	0.800
	W	52.550	0.038	–	–	–	0.0001	1.310	0.782
CSR (%)	A	19.247	0.048	–	–	–	0.0001	1.443	0.849
	W	-12.409	0.081	–	0.401	–	0.0001	2.149	0.865
CRI (%)	A	36.060	-0.0085	–	–	–	0.0292	1.186	0.207
	W	42.437	-0.0175	-0.0050	–	0.023	0.0001	0.574	0.879

A=Appalachian Blend W=Western Canadian Blend